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# YEAST, A VALUABLE PRODUCT FROM WASTES

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YEASTS are microscopic plants which like so many other vegetable products have been associated with the progress and development of the human race. They have been found on pieces of bread exhumed with Egyptian mummies. They have been used by Egyptian priests in the preparation of a dark beer for ordinary folk and a light beer for nobility. The hardy Norsemen who braved the wintry seas drank milk fermented by yeast. Mention is made in the Bible of such yeast products as leaven, wine, and mead. In the Far East, Near East, Africa, and other continents, the beneficial effects of yeast products were known and are still enjoyed.

Yeast, to many of us, is still that crumbly mass used for raising dough. A definition, 175 years old, states that yeasts are those bodies existing in a liquid during fermentation which are driven to the surface and then settle on the bottom. Later, yeasts were considered as those microscopic organisms which when placed in sugar solutions decompose these solutions to alcohol and carbon dioxide. More recently they have been divided into five utilitarian groups: beer yeasts, distillery yeasts, baking yeasts, wine yeasts, and food or feed yeasts.

The yeasts were first described in 1680 by Leeuwenhoeck, the famous Dutch cloth merchant who constructed microscopes for a hobby. In 1859 Pasteur definitely established their nature as living organisms.

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**TABLE 2**
**Comparative Composition of Beef and Yeasts**

| | *Water,* % | *Protein,* % | *Fat,* % | *Ash,* % |
|---|---|---|---|---|
| Beef Sirloin | | | | |
| Fresh | 61.9 | 18.9 | 18.5 | 1.0 |
| Baked | 63.7 | 23.9 | 10.2 | 1.4 |
| Dry | 0 | 66.0 | 28.1 | 3.9 |
| Yeast | | | | |
| Compressed | 73.0 | 14.2 | 0.4 | 2.4 |
| Dry | 0 | 52.6 | 1.5 | 8.8 |
| Torulopsis | | | | |
| Compressed | 73.0 | 15.1 | 1.2 | 2.2 |
| Dry | 0 | 56.0 | 4.6 | 8.2 |

However, Liebig and others objected to the idea that these animalcules produced alcohol as in a still. It took Büchner's discovery of zymase to clarify the viewpoints of these antagonistic scientists. This enzyme was obtained from yeast and produced alcohol in the absence of yeast. (This discovery did not mollify Liebig and Pasteur and these famous men remained enemies to the end.)

Yeasts are now recognized as fungi or molds which are oval or spherical in shape. In other words, a yeast is a mold with a special morphology. They are unicellular fungi that reproduce asexually by budding and reproduce sexually by means of spores that form within the cells. They vary in shape from a sphere to an ellipse, being 1 to 5 microns in width and 1 to 9 microns in length. (25,000 microns are equal to an inch.) Yeasts are known as *Saccharomyces* or sugar fungi. Their place in plant classification is shown in Table 1.

**TABLE 1**
**The Position of Yeasts in the Plant Kingdom**

| | | | | | |
|---|---|---|---|---|---|
| Kingdom | Plant | | | | |
| Phylum | *Spermatophytes* (seed plants) | *Pteridophytes* (ferns) | *Bryophytes* (mosses) | *Thallophytes* (fungi & algae) | |
| Class | *Phycomycetes* (algal fungi) | *Ascomycetes* (sac fungi) | *Basidiomycetes* (club fungi) | *Fungi imperfecti* (sexual phase) (unknown) | *Schizomycetes* (bacteria) |
| Order | *Saccharomycetales* | | | | |
| Family | *Saccharomycetaceae* | *Endomycetaceae* | *Torulopsidaceae* (false yeast) | | |
| Genus | *Saccharomyces*, etc. | *Endomyces*, etc. | *Torulopsis* | | |
| Species | *S. cerevisiae* | *S. fragilis* | *T. utilis* | | |

Why are yeasts of interest? Stated plainly: They rapidly convert simple sugars and inorganic salts to more desirable complex products such as protein, fats, sterols, vitamins, enzymes, glycerol, and alcohol. In 1945 this country used 8,200,000 lb. of dried yeast for human nutritional purposes. Of this quantity, 5,700,000 lb. were primarily grown for the yeast itself and were not yeast obtained as a by-product. The remaining 2,500,000 lb. of yeast were recovered from breweries. An additional 8,500,000 lb. of dried brewers' yeast were used otherwise than for humans. Thus 16,700,000 lb. was utilized for all purposes. During the past war Germany produced 200,000,000 lb. of dried yeast or 100,000 tons annually. Most of this was primary yeast. A considerable quantity is still available as a by-product in this country, when we realize that a half a pound of yeast is obtained with each barrel of beer. (In 1946, 85,000,000 barrels of beer were produced and presumably consumed in the United States.)

The very similar compositions of a *Saccharomyces* and of the wild *Torula* yeast are compared with that of beef in Table 2. Both of these yeasts are fairly high in protein and low in fat. The yeasts have considerable nitrogen-free extract not present in meat. It is not surprising that so many yeast factories were found in Germany. At present, the interest of some tropical countries, rich in carbohydrate resources, has attention centered on the microscopic yeast plant. For instance, the protein in 500,000 lb. of yeast is equal in quantity to the protein in 500 steers, each weighing 1000 lb. On some days Chicago receives a total shipment of 10,000 steers containing the same amount of protein as 10,000,000 lb. of yeast. Only four-fifths of the calculated protein of yeasts is true assimilable protein, as measured by the yield of amino acids upon hydrolysis.

Dried yeasts are readily assimilated and the proteins have a high biological value. However, something went askew when yeasts were fed as the only source of protein to rats and chicks. Only two-thirds as much growth was obtained as when chicks were fed casein. A careful study of the protein composition gave a clue to these adverse results. The sulfur-containing amino acids were the culprits. Earlier investigation had shown that these animals require certain amounts of methionine in the diet. Cystine may replace some of the methionine. The amounts of these amino acids found in proteins obtained from yeast, meat, and casein are shown in Table 3. Also shown are the amounts required in the diets of chicks and rats. Even in the 40 per cent yeast ration which contained 21 per cent protein, growth was stunted. Calculations showed the presence of only about two-thirds of the minimum chick requirements of these amino acids. Naturally, a deficiency in growth occurred! Supplementation of the yeast ration with sufficient sulfur-containing amino acids resulted in good growth. Yeasts were not toxic, as had been believed, and as much as four-fifths of the animal proteins could be replaced by yeast proteins.

**TABLE 3**
**Sulfur-containing Amino Acids in Proteins and Their Requirements in Diet**

| Protein source | Sulfur-amino acids: Cystine, % | Methionine, % |
|---|---|---|
| Yeast | 0.2 | 2.0 |
| Muscle | 1.1 | 3.3 |
| Casein | 0.3 | 3.1 |
| | *Required in daily ration* % | % |
| Rat | 0.08 | 0.5 |
| Chick | 0.4 | 0.55 |

Cattle feeds usually do not contain yeasts, although a dairy cow requires one pound of digestible protein daily. A pound of protein is also required for each thousand pounds of steer, while a yearling requires one and three-quarter pounds a day. Some milch cows are fed yeast pellets but not as a source of protein. Formulas for calf starters contain about three per cent yeast. Dog foods and rations for fur-bearing animals contain yeast. An important ingredient of fish food is yeast. (Of passing interest is the fact that the feed bill of the nation's fish hatcheries amounts to over a million dollars.) People who market honey may be aware of the pollen substitute consisting of one part yeast and six parts soybean flour. Although yeasts are high in proteins their primary use in rations is not for nitrogen content but rather as sources of growth-promoting substances.

**TABLE 4**
**Vitamin Content of Some Yeasts and Daily Human Requirement (DHR) of These Vitamins**

| | Yeast strains, mg./100 g.: *Primary* | *Brewer* | *T. utilis* | *DHR, mg./70 kg. man* |
|---|---|---|---|---|
| Thiamine | 13.6 | 2.9 | 0.3 | 1.0 |
| Riboflavin | 3.8 | 6.2 | 5.1 | 2.0 |
| Niacin | 52.5 | 28.3 | 29.7 | 10.0 |
| Pyridoxine | 4.0 | 3.4 | 1.6 | 5.0 |
| Pantothenate | 7.0 | 9.6 | 4.9 | 5.0 |
| Folic acid | 0.4 | 0.7 | 0.7 | 2.5 |

The yeast cell has the ability of manufacturing and storing many dietary essentials or factors necessary for proper utilization of proteins and minerals by animals and for the maintenance of good health. Two major deficiency diseases, beriberi and pellagra, are practically no longer extant owing to the contribution of yeast. It is the richest natural source of the B-complex vitamins. Some of the vitamin content of three selected yeasts and the daily vitamin requirements for a person of 154 lb. (70 kg.) are shown in Table 4. The variation in yeasts is clearly shown in this table.

Ergosterol, which upon ultraviolet radiation becomes vitamin D, is present in yeast in quantities ranging from 0.14 to 1.44 per cent of its weight. Ergosterol synthesis may be stimulated by feeding acetates to the yeast, just as may be done with the common black mold. This finding may be of value in the production of cortisone. The sterol forms during early stages of growth and constitutes about 18 to 20 per cent of the yeast fat. Most yeasts contain 2 per cent fat, but 5- to 15-fold increases are obtained when such acetates are fed and if the solutions are properly aerated. Yields as high as 50 per cent of yeast weight have been reported.

Mention is only made in passing of the production of enzymes, nucleates, pure proteins, and other materials from yeast.

Yeasts offer a means of converting certain wastes, surpluses, and low-cost carbohydrate materials into a product of value for animal feeding. The manufacture of feed or fodder yeast has been studied in some detail as a means of extending animal feeds, and at the same time as a means of reducing stream pollution. The soluble sugars and similar high-oxygen-demanding substances are converted to insoluble and innocuous yeast cells that may be recovered.

Fundamentally, the process does not appear to be complicated. Place some sugar water, nitrogen salts, and other nutrients in a container. Add some yeast and then force air vigorously through the solution. If the proper sugar is used, if sufficient nitrogen is present, if the nitrogen is usable, if sufficient other nutrient salts are present, if the proper yeast is added, if aeration is sufficient, and if nothing goes wrong—presto!—some hours later you may have yeast. Just that simple, but those "ifs" must be outmaneuvered.

Given a waste material containing sugar, it is first necessary to obtain a desirable yeast that will grow rapidly and produce high yields of proteins and vitamins under available conditions. Most yeasts grow on hexoses, some use pentoses, while others can also use disaccharides. A *Saccharomycete* is usually used with molasses, although a *Torula* gives good yields, too. In a recent study, *S. fragilis* gave better results than *T. utilis* and a number of other yeasts when grown on skim milk or whey. Preliminary studies may be made in simple gas-washing bottles.

After the desired yeast has been selected it is acclimatized by repeated culturing in the substrate. The highest conversion of sugar to yeast is obtained at low concentrations of sugar. At 0.5 per cent sugar concentration, yeast yields are over 45 per cent of the sugar available, dropping to as low as 10 per cent yields in the presence of 7 per cent sugar. The sugar level in industrial propagations is kept at the low values by feeding the sugar nutrient solution at varying rates into a vigorously growing culture. The starter varies from about one-twentieth to one-fifth of the final volume and has a yeast cell concentration of about 100,000,000 per ml. These increase to 500,000,000 or even to a billion during propagation. Meanwhile the amount of liquid in the tank has increased many times. The increase in total cell numbers is tremendous. Under ideal conditions yeasts double in numbers every two hours, and recent reports show that a new generation may be obtained every hour. The sugar in a 2 per cent solution was used in about 12 hours to give 500,000,000 yeast cells per ml.

Nitrogen is an important requirement for high yields. Sometime ago it was believed that the only desirable source of nitrogen was that obtained by malting grain. Since 1914 ammonium sulfate and ammonia have been used extensively in commercial operations. Other salts serve also. When using these inorganic salts the assimilation of nitrogen is practically complete. On the other hand, the nitrogen in many amino acids is only partially assimilated and hence is found in the beer. For example, glycine is completely used, serine is only 53 per cent available and about 98 per cent of the lysine is left. The ammonium molecule is preferred by yeast, and nitrates are of no value for most of them.

The amount of nitrogen required is usually determined experimentally by actual growth. Good propagations result when the amount of available nitrogen to available carbon in the mash is in the proportion of one to twelve, although a closer ratio may be desirable. From the carbon, nitrogen, hydrogen, and oxygen content of the yeast and bacteria cells, as shown in Table 5,

**TABLE 5**
**Analyses and Empirical Formulas of Microorganisms**

| | *Yeast, %* | *Bacteria, %* |
|---|---|---|
| Carbon | 47.0 | 47.3 |
| Hydrogen | 6.0 | 5.7 |
| Oxygen | 32.5 | 27.0 |
| Nitrogen | 8.5 | 11.3 |
| Ash | 6.0 | 8.3 |
| Empirical formula | $C_{13}H_{20}N_2O_7$ | $C_{10}H_{14}N_2O_4$ |
| Carbon–nitrogen ratio | 5.6/1 | 4.3/1 |

the composition formulas were calculated. These are only empirical formulas containing the four major elements and in no way show the complexities of living cells. The carbon to nitrogen ratio of the yeast is 47:8.5 or 5.5:1. Studies on aerated dairy wastes show that under vigorous aeration about 62.5 per cent of the carbon available in solution is assimilated and converted to cell material having the formula shown for bacteria. Thus, three-eighths of the carbon is burned to carbon dioxide in this rapid growth process. Therefore to supply the 5.6 parts carbon in the yeast cell at least 9.1 parts will be necessary in the original mash for each part of nitrogen. A hundred pounds of sugar containing 40 lb. of carbon should yield 54 lb. of yeast containing 25 lb. of the carbon.

The maximum yield may be determined in another way. The classical equation for fermentation

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

shows that 180 lb. of sugar is converted to 92 lb. of alcohol and 88 lb. of carbon dioxide. In the propagation process, where sufficient air is used, the alcohol does not accumulate but is converted to a yeast cell which ties up four of the six carbons. The carbon utilized in this case is two-thirds of that originally present and the 100 lb. of sugar should yield 57.5 lb. of yeast. Actual yields are somewhat less than this optimum value. Knowing this, we can now calculate that 100 lb. of sugar requires 4.5 lb. of nitrogen which may be supplied by 22.5 lb of ammonium sulfate.

Except for experimental purposes, pure sugars are not used for yeast propagation. Molasses may be used if the price is right, but it has greater value for alcohol production. Sulfite liquors from the wood pulping industries which create terrific pollution effects can serve as a sugar source for yeast. This waste liquor may be treated with lime, filtered, treated with sulfuric acid, and filtered again. The resulting solution contains 2 to 2.5 per cent sugar and supports good yeast growth when nitrogen, phosphates, and other nutrients are added. At least one such plant operates in this country and one in Canada.

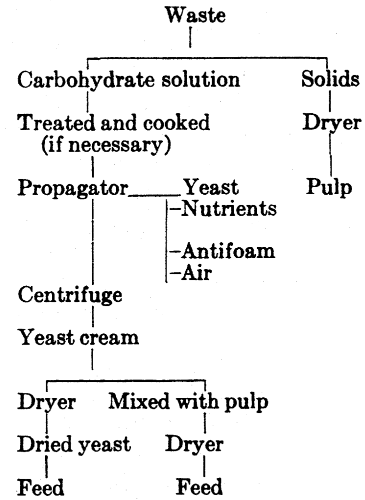
Waste wood itself, such as sawdust, twigs, and chips, may be hydrolyzed by strong acids. After neutralization and filtration the resulting solution contains 4.5 per cent sugar and produces good yeast. Such a process was used in Germany and is being tried experimentally in this country on the West Coast. The mild hydrolyzates of straw prepared for paper have been used. In Jamaica and other islands of the West Indies cane and other plant juices yield solutions containing 10 per cent sugar. Feed yeast has also been prepared from citrus waste press juice containing about 6.5 per cent sugar after clarification. Fruit waste juices available at canneries on the West Coast may be readily used, since they contain 7 to 11 per cent sugar and require no special treatment. *Torula* yeast has been grown on waste waters from the processing of sweet potatoes for starch. This waste contains one per cent sugar and clarification is not necessary. The recovered material contained a mixture of yeast and coagulated proteins which could be added to the pulp feed. In the preparation of protein from peanuts a waste containing one per cent sugar is available which gave good yeast yields. Skim milk and whey are also good sugar sources.

It is now obvious that any sugar water can serve for yeast growth if the right fertilizer or nutrient salts are added and if the right organism and desirable conditions are available.

One of these important conditions is a sufficiency of air. When making wine it is necessary to exclude air and keep the mash undisturbed. Good yeast growth requires the opposite régime. Vigorous aeration and agitation are necessities. Means of supplying sufficient air to the rapidly growing yeast is continually under study and is a major engineering difficulty. Industrially, the critical problem is air supply. Studies on dairy waste disposal and penicillin production show that in order to maintain aerobic conditions the oxygen in solution must not drop below 0.3 parts per million. At a propagation temperature of 30°C. a water solution saturated with air has slightly over 5 parts per million of oxygen. In a solution containing only 0.05 per cent sugar and about 300 parts per million of sludge bacterial cells, the oxygen is used up so rapidly that the solution becomes anaerobic in less than 10 minutes. We can well imagine what happens in a highly concentrated yeast mixture with its exorbitant demand for oxygen. No wonder that in many propagation studies the odor of alcohol is perceptible. Air is commonly supplied by ordinary spargers consisting of perforated tubes, although porous stone plates have been tried. A newer type propagator, known as the Waldhof fermentor, permits growth of the yeast in the foam which is continually drawn back into the solution by a rapidly spinning, wheel-like mechanism. This apparatus favors rapid propagation and has found use on a continuous process using sulfite waste liquor.

**TABLE 6**

**Schematic Utilization of Waste for Feed Yeast Production**




After the growth period the yeast is concentrated by means of centrifugals. The yeast cream, containing about 20 per cent solids, is dried on a steam-drum dryer or a spray dryer. The cream may be added directly to the waste vegetable pulp prior to drying the mixture in a rotary dryer. A schematic presentation of the utilization of a waste for yeast growth and feed is shown in Table 6.

The question arises as to the future of feed yeasts. Considerable time and energy are being devoted to the study of the production and utilization of yeasts. As mentioned earlier, a fair portion of the protein in chick and turkey feed can be supplied by yeasts. Livestock feeds offer a tremendous outlet for yeast if the price is right. The disposal of liquid wastes by many industries using agricultural products is a major problem. Many use aeration tanks for this purpose. Combining the two processes, the aerobic disposal of wastes and the aerobic propagation of yeast should permit the recovery of an important feed supplement. The stream pollution effect of these high-oxygen-demanding wastes would be reduced tremendously. At the same time an additional useful product rich in health and growth-promoting factors would become available. Such use is possible with many types of wastes; the soluble constituents would be converted to insoluble removable cells without special processing. Such recovery may eventually be required in all processing plants to alleviate the disposal or pollution problem and to help increase the available food supplies for the 200,000,000 people anticipated in this country by the year 2000.